Timber and carbon sequestration

This article discusses carbon sequestration and end-of-life processes in timber structures, and the implications for sustainable decision-making in structural design.

Introduction

The first step towards reducing the embodied carbon of construction is calculating it reliably and repeatably, and it is therefore timely that a strong consensus has formed around a life cycle assessment (LCA) methodology based on EN 15978 [1]. This standard underpins the recent guidance from the IStructE [2], and breaks a product's life cycle down into production (Module A), use (B), end-of-life (C) and potential recovery/re-use (D). As more of these stages are included within an LCA's scope, a more complete picture of impacts is provided. However, often only module A is included due to the considerable uncertainty surrounding end-of-life processes.

For steel and concrete, which both feature high-energy production processes, module A dominates life cycle emissions. The production emissions for timber products, from harvesting, drying and sawing, are also significant, however the mass of carbon absorbed by the tree and stored within the material itself can be even greater. Although this is typically re-released at end-of-life due to combustion and/or decomposition, there are climate benefits of sequestering atmospheric carbon within long-lived timber products which act as a carbon-sink [3]. For example, delaying carbon emissions reduces cumulative climactic energy input, buys time for adaptation of both natural and man-made systems, reduces the possibility of reaching dangerous climate 'tipping-points', and increases the potential for permanent storage through future technologies such as carbon capture and storage.

However, accounting for sequestered carbon is often a source of debate, confusion and inconsistency. When sequestration is reported within Module A, or alongside it as a negative emission, it can create the counter-intuitive impression that using timber excessively can have environmental benefits. The IStructE guide therefore advises that sequestration should only be aggregated with emissions when end-of-life is also included, where the stored carbon is typically cancelled out by re-emission at end-of-life.

This article provides a rational approach to the incorporation of sequestration in embodied carbon calculations, and provides recommendations for effective climate-focused timber design: sustainable sourcing, long lifespans and efficient use of materials.

Rationalising timber sequestration

Growing trees and locking away carbon in timber buildings has been proposed as a potentially significant carbon sink [3]. But would it be better, from a carbon perspective, to leave forests to grow naturally? Figure 1 shows the changes in carbon storage within a typical commercially managed Sitka spruce forest with a harvesting cycle of 50 years, using data from a Forestry Commission report [4], and compares this with an equivalent unmanaged forest. This reveals several important points.

Carbon uptake in newly planted saplings is initially slow, but then accelerates as these become established. In an unmanaged forest, sequestration continues until the total carbon eventually tends towards a steady-state. A managed forest also achieves a constant carbon storage, albeit cyclic between each harvesting period and lower than that of an unmanaged forest. However, it also stores carbon in the products produced from it. If these are amassed sufficiently over time, then the total carbon sequestered accumulates and could eventually be greater than that of an unmanaged forest.

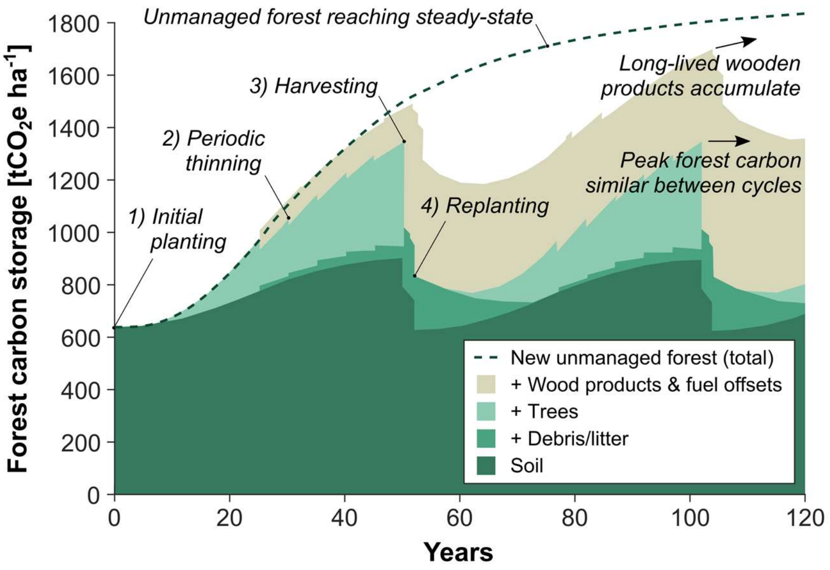

Figure 1 –Carbon stored in trees, debris/litter and soil for a typical Sitka Spruce plantation with 50 year rotation period, compared to a forest left unmanaged, with data from the Forestry Commission [4].

Considering these observations, the approach to sequestration taken in this article is based on the following principles:

- Although an understanding of the variation in carbon stored within a forest is informative, this carbon is not typically included in a building's LCA scope. Instead, only the carbon in the timber product itself should be included, in line with typical product LCA methodologies [5].
- Harvesting, processing and constructing a timber building releases a 'spike' of carbon into the atmosphere, whereas sequestration occurs gradually.
- Carbon accounting should always start at zero – credit should not be taken for a tree planted 50 years ago, even if this eventually ends up being used to build the structure under investigation.
- Where trees are harvested and not replaced (deforestation), no sequestration should be accounted for, in-line with current European standards [5].

This article recommends using sequestration values corresponding to the timber structure itself, such as those given in the ICE database [6] and IStructE guidance [2], rather than the entire forest from which it came. However, the assumed timing of sequestration is that of the trees which replace those harvested, starting from zero and increasing until the next harvesting cycle, assumed here to be 50 years. This 'forward-looking' approach is characterised and recommended by Helin et al. [7], and its implications are explored hereafter.

Comparing a concrete, steel and timber building

This section compares the embodied carbon of concrete (flat slab), steel (composite) and timber (CLT with glulam frame) options for a six-storey building structure. The designs are those featured in a recent Buro Happold study [8], with all options featuring a concrete core and foundations. The calculation methodology follows IStructE guidance [2], and is detailed in a separate publication [9]. The analysis is cradle-to-grave; Module D benefits (beyond the system boundary), which are reported separately in current standards [1], are not included. This has the same effect as assuming that all material production is effectively decarbonised by the end of the building's 60 year lifespan, in line with UK law, since offset materials would also be zero carbon.

Three carbon life cycles are considered for timber:

1. Typical sustainably sourced UK timber with re-planting (sequestration) and a large carbon emission at end of life from recycling (55% by mass), incineration with energy recovery (44%) and landfill (1%) [10], as given in the IStructE guidance [2].

2. As above, but without re-planting or sequestration, representing a worst-case scenario (non-sustainably sourced timber, uncommon in the EU).
3. An optimistic scenario which combines sustainable forest management (sequestration) with minimal emissions at end-of-life. It has been suggested that up to 90% of combustion emissions could potentially be captured using bioenergy with carbon capture and storage (BECCS) [11]. This has been represented here by a 90% reduction in Module C3-4 emissions. Carbon capture is not permitted in a standard LCA [5], but is considered here as a hypothetical scenario.

The cumulative carbon emissions over a 120 year period for each structure are shown in Figure 2. The concrete structure has the highest initial (Module A) emission, followed by steel and then timber, for this structural arrangement. For concrete and steel, the use and end-of-life stages see only small changes in embodied carbon. For timber, however, subsequent changes are significant.

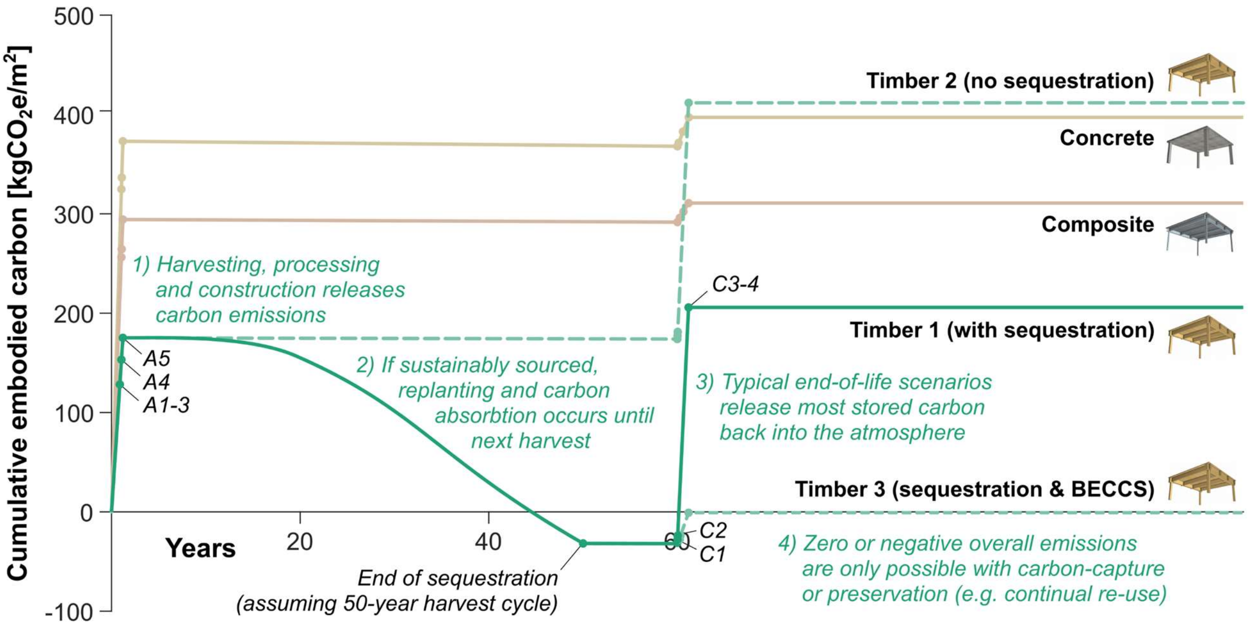

Figure 2 – Cumulative embodied carbon emissions for concrete, steel and timber options of the example building structure [8], *including three scenarios for timber components.*

In timber scenario 1, sequestration causes a small, temporary period of negative carbon emissions. This lasts only while the building is in-use, ending abruptly upon demolition. If the structure is in-use for 100 years, it would be carbon negative for half its lifetime, whereas the same structure demolished after 40 years would never reach negative carbon. The dynamic climate impacts of this temporary carbon storage are considered, for a similar case-study, in a separate publication [9]. Despite the large Module C emissions, the total cradle-to-grave carbon is still lower than the concrete and steel options in this scenario.

In scenario 2, without sequestration, the significant release of carbon at end-of-life causes the timber option to have the largest total embodied carbon. This highlights the essential importance of sustainable timber sourcing which includes replanting, as is typical in the EU.

Scenario 3 shows the potential for a zero-carbon timber building if end-of-life emissions can be avoided. This is an optimistic scenario, relying on technology which does not currently exist at a meaningful scale. It would therefore be misleading to consider this in a typical embodied carbon calculation, and not permissible using today's standards [1, 5]. Even in this event, the large initial emission from construction is not avoided, and still contributes to global warming for several decades [9].

It can therefore be concluded that, even under best-case conditions, it is still better (for the climate) to build nothing at all than a timber building.

Although this study shows concrete as the highest carbon, and timber the lowest, these results are specific to the designs in question and do not represent a fixed hierarchy. This timber design is very light, featuring 100mm thick CLT floors, and the concrete flat slabs are relatively inefficient at 9m spans compared to ribbed or post-tensioned alternatives. Figure 3 illustrates the point that a wasteful or inappropriate use of timber could readily have a greater impact than a more efficient concrete/steel alternative: it is always better to use less of any material. We cannot quickly increase total timber supply, and must therefore use this valuable resource sparingly to enable maximum potential uptake across the sector.

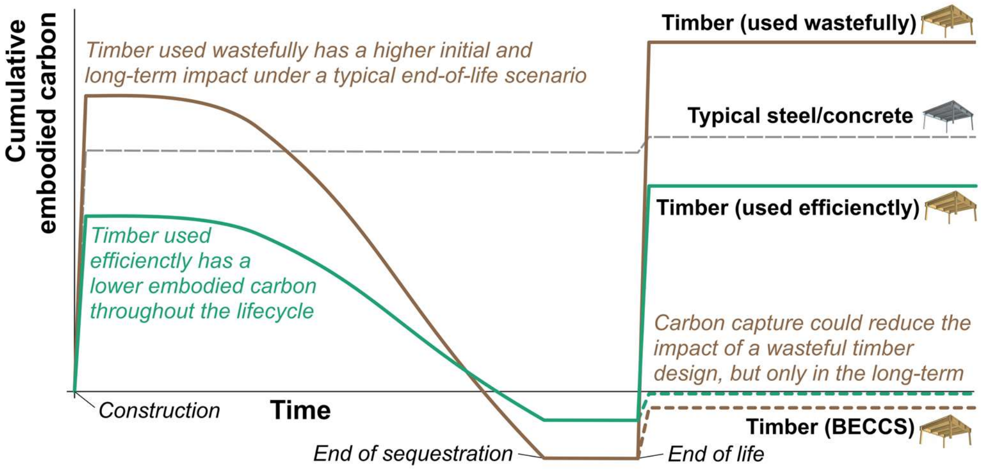

Figure 3 –Wasteful use of timber could have a greater impact, in both the short and long-term, than an efficiently designed concrete and steel alternative.

Conclusions

This article has demonstrated an approach to accounting for timber carbon sequestration in line with established guidance. Through a simple case-study, several conclusions can be drawn:

- Timber must be sustainably sourced, with replanting, for any potential embodied carbon benefits over concrete and steel to be realised. Thankfully, sustainability certification schemes (such as the PEFC and FSC) are well established and often a legal requirement for import.
- End-of-life carbon fluxes are significant for timber structures. The climate benefits of timber can therefore be maximised by prolonging the life of structures, re-using timber components or recycling into new materials, all of which keep sequestered carbon out of the atmosphere.
- It is hypothetically possible for timber to have a negative cumulative embodied carbon, in the long term, when it is both sustainably sourced and end-of-life emissions are also avoided, for example through new technologies such as BECCS. This cannot be relied upon in a typical embodied carbon analysis, however, and several decades of net positive emission still occur.
- It is better to build nothing at all than a timber building. Similarly, wasteful use of timber can be more damaging than an efficient design in concrete and steel.

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